UCRL-JC-124237 Abs

Low defect reticle blanks for extreme ultraviolet lithography

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Reticles are the fundamental challenge for future lithography systems. Defects in the reflection reticle used in extreme ultraviolet lithography (EUVL) are a potential "show stopper". Our work has resulted in a reduction in reticle defects *by five orders of magnitude*. This result dramatically reduces the risk associated with EUVL.

Reticles for EUVL consist of a high reflectance multilayer (ML) coated substrate (reticle blank) that is overcoated with a patterned absorber layer to form a reflective reticle. Any reflectance variation in the reticle constitutes a potential reticle defect. The ML reflective coating operating at 13 nm consists of 40 layer pairs of 4 nm of Si and 3 nm of Mo capped with a 30 nm Si protective layer. As with all other advanced lithography systems, reticle defects represent a fundamental limitation to the practical implementation of the technology. In EUVL, the deposition of the ML coating with low defect density represents an enabling technology for EUVL.

In a study completed in 1994, typical particle counts in sputtered Mo/Si MLs were of order 10,000/ cm^2 @ ≥ 0.25 μm, five orders of magnitude greater than is required for prototype work. The operation of a prototype EUVL systems with a no reticle defects requires defect densities of less than $0.1/cm^2$ for defects larger than 0.13 μm. We recognized that the semiconductor industry has developed highly refined procedures for the deposition of low defect density, single component films utilizing magnetron sputtering technology; however, extension of these techniques to the fabrication of highly uniform Mo/Si MLs is not straightforward. In fact, the range of deposition parameters associated with low defect generation is generally inconsistent with the requirements for high quality ML fabrication[1].

We have developed a new deposition tool using ion beam sputter deposition (IBSD). This method offers several advantages in comparison to magnetron sputtering that are consistent with low defect generation including reduced system complexity, lower deposition pressure and superior electrical isolation of the substrate and sputtering target. The system incorporates: (1) standard mechanical interface (SMIF) modules, (2) a class 1 minienvironment and (3) ultra-low particle transfer robots to protect the blank from environmental contamination during handling. Carefully controlled pump/vent protocols developed in conjunction with real-time feedback from *in situ* particle monitors minimize wafer contamination during wafer introduction and deposition. 150 mm diameter Si wafers were employed as substrates. They are readily available, clean, have extremely smooth surfaces and enable the use of standard semiconductor diagnostic tools. A Tencor 6420, dark field defect detection system was used to measure the coating defect density. The instrument has a detection efficiency of greater than 95% for particles greater than 0.13 μm in diameter.

We report the fabrication of 81 later Mo/Si ML coatings with a measured defect density as low as $0.027\ cm^{-2}$ using the new deposition tool. The defect density includes all particles greater than 0.13 μm in diameter measured on a 150 mm diameter wafer with a 15 mm exclusion zone: this corresponds to a total count of 3 particles within the detected area of 113 cm^2. Two defects were added in the full 81 layer deposition process corresponding to

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[1] S.P. Vernon, D.G. Stearns and R.S. Rosen, Applied Optics **32**, pp. 6969-6974 (1993).

a process generated defect density of 0.018 cm^{-2}. These results represent a significant advance in EUVL reticle technology and enhance the prospects for practical implementation of EUVL. We can now define a clear engineering path to defect free reticle fabrication. Extensions of the low defect density IBSD ML deposition technologies to more conventional thin film deposition processes have the potential to produce higher yields in both semiconductor manufacturing and information storage industries.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.